REMARKS

In view of the above amendments and the following remarks, reconsideration of the rejections contained in the Office Action of August 28, 2002 is respectfully requested.

The Examiner has requested the Applicants' cooperation in correcting any errors of which the Applicants may be become aware in the specification. In view of this request, the entire specification and abstract have now been reviewed and revised. As the revisions are quite extensive, the amendments to the specification and abstract have been incorporated into the attached substitute specification and abstract. For the Examiner's convenience, a copy of the marked-up original specification and abstract is also enclosed, and the marked-up pages are captioned "Version with Markings to Show Changes Made." The substitute specification and abstract includes the same changes as are indicated in the marked-up copy of the original specification. No new matter has been added by the revisions. Thus, entry of the substitute specification is respectfully requested.

The Examiner has rejected claims 1-40 under 35 U.S.C. § 112, second paragraph, as being indefinite. In particular, the Examiner has cited several examples of informal or vague language that renders the scope of the claims unclear. In view of these rejections, original claims 1-40 have been cancelled and replaced with new claims 41-80. Although the new claims correspond to the original claims and the scope of the new claims has not been narrowed, the new claims have been drafted so as to address the rejections under 35 U.S.C. § 112 and so as to fully comply with all of the requirements of 35 U.S.C. § 112. Therefore, it is respectfully submitted that the Examiner's rejections under 35 U.S.C. § 112 are not applicable to the new claims.

The Examiner has rejected claims 1-40 under the judicially-created doctrine of double patenting in view of U.S. Patent No. 6,346,915 (the '915 patent). However, this double patenting rejection is respectfully traversed for the reasons set forth below.

The '915 patent is directed to a plasma processing method and apparatus that is somewhat similar to the present invention. In particular, the '915 reference teaches that the gas supply device 2 supplies gas into the vacuum chamber 1 during plasma processing. However, the '915 patent <u>does not</u> claim or even teach that gas is introduced into the interior of the vacuum chamber *through a hole*

in a dielectric tube attached to a metal body fixed to the vacuum chamber. Furthermore, the '915 patent does not claim or even teach an apparatus including *a dielectric tube having a gas supply hole formed therethrough*, and being operable to allow the gas supplied to the vacuum chamber by the gas supply device to pass through the gas supply hole so as to enter the vacuum chamber. Since each of the new claims 41-80 recite either introducing the gas through a hole in a dielectric tube, or a dielectric tube having a gas supply hole formed therethrough, and since the Okamura reference does not claim or even teach this feature, the Examiner is respectfully requested to withdraw the double patenting rejection.

The Examiner has rejected claims 1-40 as being unpatentable over the Tsukamoto reference (USP 5,868,848). However, as indicated above, original claims 1-40 have been cancelled and replaced with new claims 41-80, including new independent claims 41, 56, 57, and 72. Although the scope of the original claims has not been narrowed in drafting the new claims, it is submitted that the invention recited in the new claims is clearly distinguishable from the prior art. Thus, for the reasons discussed below, the Examiner's rejection is respectfully traversed, and it is submitted that new claims 41-80 are clearly patentable over the prior art of record.

New independent method claims 41 and 56 recite that a gas is introduced into an interior of a vacuum chamber *through a hole in a dielectric tube*. In addition, new independent apparatus claims 57 and 72 recite that the plasma processing apparatus comprises *a dielectric tube having a gas supply hole formed therethrough*, and which is operable to allow the gas supplied to the vacuum chamber by the gas supply device to pass through the gas supply hole so as to enter the vacuum chamber.

As explained on page 2, line 15 - page 3, line 8 of the original specification, the flow of gas into a vacuum chamber during plasma processing of a substrate creates a hollow cathode discharge. In conventional plasma processing methods and devices, this hollow cathode discharge causes deterioration of the gas supply hole, and also causes contamination of the substrate with metal particles eroded from the gas supply hole by the hollow cathode discharge (see page 3, lines 4-8 of the original specification). In view of these problems, the present invention is directed to a plasma processing method and apparatus, in which gas is introduced into the vacuum chamber through a *dielectric tube*. Therefore, as explained on page 19, line16 through page 20, line 4 of the original

specification, the hollow cathode discharge is significantly reduced or eliminated. As a result, deterioration of the gas supply hole, and contamination of the substrate being processed, is also significantly reduced or eliminated.

The Tsukamoto reference discloses a plasma processing apparatus in which gas is supplied into a vacuum chamber 2 through diffusion holes 22 in an upper electrode 21 (see column 4, lines 35-44). However, the Tsukamoto reference does not disclose or suggest that gas is introduced into the interior of the vacuum chamber through a hole in a *dielectric tube*, or disclose or suggest a plasma processing apparatus that comprises *a dielectric tube having a gas supply hole formed therethrough*, and which is operable to allow the gas supplied to the vacuum chamber by the gas supply device to pass through the gas supply hole so as to enter the vacuum chamber. Therefore, because the Tsukamoto reference does not disclose or suggest a gas supply hole in a dielectric tube for allowing passage of gas into the vacuum chamber, one of ordinary skill in the art would not be motivated to modify the Tsukamoto reference in order to obtain the invention recited in new claims 41-80. Accordingly, it is respectfully submitted that new claims 41-80 are clearly patentable over the prior art of record.

In view of the above amendments and remarks, it is submitted that the present application is now in condition for allowance. However, if the Examiner should have any comments or suggestions to help speed the prosecution of this application, the Examiner is requested to contact the Applicants' undersigned representative.

Respectfully submitted,

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Version with Markings to Show Changes Made

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SPECIFICATION

TITLE OF THE INVENTION

Plasma Processing Method and Apparatus Thereof

BACKGROUND OF THE INVENTION

The present invention relates to a plasma processing method and an apparatus thereof for use in manufacturing electron devices and micro machines made of semiconductors ~~and others~~.

In recent years, A thin film processing technique using plasma processing HAS become~~s~~ more and more important in the field of manufacturing semiconductor electron devices and micro machines.

As one example of prior art plasma processing methods, plasma processing with use of an inductively coupled plasma source will be described hereinbelow with reference to Fig. 8. In Fig. 8, a specified gas is introduced from a gas supply device 2 into a vacuum chamber 1 while being exhausted therefrom by a pump 3 serving as an exhauster to keep the vacuum chamber 1 within A specified pressure. Under such a condition, high-frequency power of 13.56 MHz can be supplied by a high-frequency power source 4 ~~for coil 4~~ to a coil 23 to generate plasma~~s~~ in the vacuum chamber 1 to perform plasma processing of a substrate 7 mounted on a substrate electrode 6. In addition, there is provided a high-frequency power source for substrate

electrode 8 for supplying high-frequency power to the substrate electrode 6, which enables control of ion energy REACHING ~~reached~~ the substrate 7. It is noted that the coil 23 is disposed on top of a dielectric window 24. The gas is introduced into the vacuum chamber 1 through a plurality of gas supply holes 25 provided on a metal ring 16 which constitutes part of a side wall of the vacuum chamber 1.

However, in order to improve fine processability and enlarge THE processing area, THE flow of gas to be used in processing should be increased, ~~and processing~~ should be performed under lower pressure. THIS ~~which~~ tends to induce abnormal electrical discharge called hollow cathode discharge in gas supply holes 25 in the prior art plasma processing.

A ~~Description~~ description of the hollow cathode discharge is as follows. In ~~General~~ general, the surface of a solid in contact with ~~plasmas~~ plasma is negatively electrified due to A difference in thermal velocity between an electron and an ion, so that the solid surface obtains direct electric fields which send away electrons from the solid surface. In a space surrounded with the solid surface, like the inside of the gas supply hole 25 shown in the prior art, A tendency FOR ~~to~~ ~~collision of~~ electrons TO COLLIDE with the solid surface is reduced due to the presence of the direct electric fields. THIS FEATURE ~~which~~ prolongs a lifetime of the electrons, resulting in

generation of high-density plasmas (for example, ~~at~~ 100 MHz) inside the gas supply hole 25. ~~Thus~~ THE generated electric discharge is called hollow cathode discharge.

The hollow cathode discharge generated in the gas supply hole 25 causes deterioration of the gas supply hole (the lapse of time causes gradual increase of the diameter of the hole) 25 and contamination of a substrate by metal substances constituting the gas supply hole 25.

It is empirically indicated ~~that~~ A larger gas velocity in the gas supply hole 25 and A larger pressure gradient in the vicinity of the gas supply hole 25 tend to induce hollow cathode discharge. In addition, A larger gas flow rate and A lower pressure in the vacuum chamber 1 also tends to induce hollow cathode discharge. Accordingly, improvement of fine processability and implementation of A larger processing area require A larger flow rate of gas for use in processing and processing under lower pressure, which clarifies THE importance of solving the issue of A hollow cathode discharge in the gas supply hole 25.

SUMMARY OF THE INVENTION

In view of the conventional issue stated above, an object of the present invention is to provide a plasma processing method and an apparatus thereof which decreases induction of hollow cathode discharge in the gas supply

hole.

In accomplishing these and other aspects, according to a first aspect of the present invention, there is provided a plasma processing method comprising:

introducing a gas into a vacuum chamber through a hole of a dielectric tube attached to a metal body fixed to the vacuum chamber while exhausting from the vacuum chamber to keep the vacuum chamber within a specified pressure; ~~and~~

~~applying~~ High-frequency power with a frequency ranging from 100kHz to 3GHz IS APPLIED to ~~a~~ plasma source ARRANGED ~~provided~~ so as to face a substrate mounted on a substrate electrode in the vacuum chamber to generate plasma~~s~~ in the vacuum chamber to perform plasma processing of the substrate.

According to AN ~~a~~ aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein ~~the~~ high-frequency power with a frequency ranging from 100kHz to 3GHz is applied to an antenna serving as the plasma source with a dielectric plate interposed between the antenna and the vacuum chamber. ~~and with~~ The antenna and the dielectric plate protrude~~d~~ ~~in~~ INTO the vacuum chamber.

According to a second aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein the high-frequency power is applied to an antenna serving as the plasma source

through a penetrating hole given near a center of the dielectric plate, ~~with~~ The antenna and the vacuum chamber ARE short-circuited with short pins through penetrating holes which are given at an area located not in a center nor a vicinity of the dielectric plate, and which are disposed at approximately equal intervals around a center of the antenna.

According to a third aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein a substrate is processed in a state IN WHICH ~~that~~ a plasma distribution on the substrate is controlled by a circular and groove shaped plasma trap provided between the antenna and the vacuum chamber.

According to a fourth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect wherein a substrate is processed in a state IN WHICH ~~that~~ a plasma distribution on the substrate is controlled by a groove-shaped plasma trap provided between the antenna and ~~the~~ metal body, THE METAL BODY ~~which~~ is a ring ARRANGED ~~disposed~~ so as to FORM ~~constitute~~ the plasma trap ~~there~~between THE ANTENNA AND THE RING.

According to a fifth aspect of the present invention, there is provided a plasma processing method comprising:

introducing a gas into a vacuum chamber through a hole of a dielectric tube attached to a facing electrode provided so as to face a substrate electrode in the vacuum chamber while exhausting from the vacuum chamber to keep the vacuum chamber within a specified pressure. ~~and~~

~~applying~~ High-frequency power with a frequency ranging from 100kHz to 3GHz IS APPLIED to the substrate electrode or the facing electrode to generate plasma in the vacuum chamber to perform plasma processing of the substrate.

According to a sixth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein A gas supply flow rate per hole given to the dielectric tube is 200sccm or less.

According to a seventh aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein A gas supply flow rate per hole given to the dielectric tube is 50sccm or less.

According to an eighth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein the gas is a mixed gas mainly composed of an argon gas.

According to a ninth aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein pressure in the vacuum chamber is 10Pa or less.

According to a 10th aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein pressure in the vacuum chamber is 1Pa or less.

According to an 11th aspect of the present invention, there is provided a plasma processing method as defined in the first aspect, wherein a frequency of the high-frequency power applied to the plasma source, the substrate electrode or the facing electrode is 50MHz to 3GHz.

According to a 12th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein A gas supply flow rate per hole given to the dielectric tube is 200sccm or less.

According to a 13th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein A gas supply flow rate per hole given to the dielectric tube is 50sccm or less.

According to a 14th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein the gas is a mixed gas mainly composed of an argon gas.

According to a 15th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein pressure in the vacuum chamber

chamber is 10Pa or less.

According to a 16th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein pressure in the vacuum chamber is 1Pa or less.

According to a 17th aspect of the present invention, there is provided a plasma processing method as defined in the sixth aspect, wherein a frequency of the high-frequency power applied to the plasma source, the substrate electrode or the facing electrode is 50MHz to 3GHz.

According to an 18th aspect of the present invention, there is provided a plasma processing apparatus comprising:

a vacuum chamber capable of maintaining a vacuum state;

a gas supply device for supplying a gas into the vacuum chamber;

an exhauster for exhausting the gas from the vacuum chamber;

a substrate electrode for mounting a substrate in the vacuum chamber;

a plasma source provided so as to face the substrate electrode;

a high-frequency power source for supplying high-

frequency power with a frequency ranging from 100kHz to 3GHz to the plasma source; and

a dielectric tube having a gas supply hole, AND BEING attached to a metal body fixed to the vacuum chamber. ~~for~~ ~~passing the~~ gas IS PASSED through the gas supply hole OF THE DIELECTRIC TUBE ~~thereof~~ when the gas is supplied to the vacuum chamber by the gas supply device.

According to a 19th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein a dielectric plate is interposed between the vacuum chamber and an antenna serving as the plasma source. ~~and~~ The antenna and the dielectric plate ~~are~~ protruded ~~in~~ INTO the vacuum chamber.

According to a 20th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 19th aspect, wherein high-frequency power is supplied to the antenna through a penetrating hole given near a center of the dielectric plate. ~~and~~ The antenna and the vacuum chamber are short-circuited with short pins through penetrating holes which are given at an area located not in a center nor a vicinity of the dielectric plate and which are disposed at approximately equal intervals around a center of the antenna.

According to a 21st aspect of the present invention, there is provided a plasma processing apparatus

as defined in the 19th aspect, wherein a substrate is processed in a state ~~that~~ IN WHICH a plasma distribution on the substrate is controlled by a circular and groove-shaped plasma trap provided between the antenna and the vacuum chamber.

According to a 22nd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the metal body is a ring that constitutes a part of a side wall of the vacuum chamber.

According to a 23rd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 21st aspect, wherein the metal body is a ring disposed so as to constitute a plasma trap between the metal body and the antenna.

According to a 24th aspect of the present invention, there is provided a plasma processing apparatus comprising:

a vacuum chamber capable of maintaining a vacuum state;

a gas supply device for supplying a gas into the vacuum chamber;

an exhauster for exhausting the gas from the vacuum chamber;

a substrate electrode for mounting a substrate in

the vacuum chamber;

a facing electrode provided so as to face the substrate electrode;

a high-frequency power source for supplying high-frequency power with a frequency ranging from 100kHz to 3GHz to the substrate electrode or the facing electrode; AND

a dielectric tube having a gas supply hole, AND BEING attached to a ~~metal~~ body fixed to the facing electrode. ~~for~~ ~~passing~~ The gas PASSES through the gas supply hole ~~thereof~~ OF THE DIELECTRIC TUBE when the gas is supplied to the vacuum chamber by the gas supply device.

According to a 25th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the dielectric tube is a bolt screwed in a tap given to the metal body or the facing electrode.

According to a 26th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the dielectric tube has a spot facing for A screwdriver or A wrench on a side of an inner wall of the vacuum chamber for rotating and screwing the dielectric tube in the metal plate or the facing electrode.

According to a 27th aspect of the present invention, there is provided a plasma processing apparatus

as defined in the 18th aspect, wherein the dielectric tube ~~is protruded by~~ PROTRUDES 0.5 to 20mm from a surface of the metal body or the facing electrode.

According to a 28th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the dielectric tube ~~is protruded by~~ PROTRUDES 1 to 10mm from a surface of the metal body or the facing electrode.

According to a 29th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 27th or 28th aspect, wherein the dielectric tube is disposed such that it covers an edge of a hole of the metal body or the facing electrode.

According to a 30th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the hole of the dielectric tube is 0.2 to 2mm in diameter.

According to a 31st aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein the hole of the dielectric tube is 0.4 to 0.8mm in diameter.

According to a 32nd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 18th aspect, wherein a frequency of high-frequency power applied to the plasma source, the substrate

electrode or the facing electrode is 50MHz to 3GHz.

According to a 33rd aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, ~~wherein~~ the dielectric tube is a bolt screwed in a tap PROVIDED IN ~~given to~~ the metal body or the facing electrode.

According to a 34th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the dielectric tube has a spot facing for A screwdriver or A wrench on a side of an inner wall of the vacuum chamber for rotating and screwing the dielectric tube in the metal plate or the facing electrode.

According to a 35th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the dielectric tube PROTRUDES ~~is protruded by~~ 0.5 to 20mm from a surface of the metal body or the facing electrode.

According to a 36th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the dielectric tube PROTRUDES ~~is protruded by~~ 1 to 10mm from a surface of the metal body or the facing electrode.

According to a 37th aspect of the present invention, there is provided a plasma processing apparatus

as defined in the 27th or 28th aspect, wherein the dielectric tube is disposed such that it covers an edge of a hole of the metal body or the facing electrode.

According to a 38th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the hole of the dielectric tube is 0.2 to 2mm in diameter.

According to a 39th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein the hole of the dielectric tube is 0.4 to 0.8mm in diameter.

According to a 40th aspect of the present invention, there is provided a plasma processing apparatus as defined in the 24th aspect, wherein a frequency of high-frequency power applied to the plasma source, the substrate electrode or the facing electrode is 50MHz to 3GHz.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings, in which:

Fig. 1 is a cross sectional view showing THE ARRANGEMENT ~~construction~~ of a plasma processing apparatus for use in a

first embodiment of the present invention;

Fig. 2 is a detail view showing the vicinity of a dielectric ~~bush~~ BUSHING for use in the first embodiment of the present invention;

Fig. 3 is a plan~~e~~ view showing an antenna for use in the first embodiment of the present invention;

Fig. 4 is ~~a cross~~ sectional view showing ~~construction of a case where~~ AN ARRANGEMENT IN WHICH the present invention is applied to a plasma processing apparatus with a surface wave plasma source;

Fig. 5 is a cross sectional view showing ~~construction~~ AN ARRANGEMENT of the plasma processing apparatus in a modified example of the first embodiment of the present invention;

Fig. 6 is a cross sectional view showing ~~construction~~ AN ARRANGEMENT of a plasma processing apparatus for use in a second embodiment of the present invention;

Fig. 7 is a detail view showing the vicinity of a dielectric ~~bush~~ BUSHING for use in the second embodiment of the present invention;

Fig. 8 is a cross sectional view showing ~~construction~~ AN ARRANGEMENT of a plasma processing apparatus for use in the prior art;

Fig. 9 is a perspective view of the dielectric ~~bush~~ BUSHING according to the first embodiment;

Fig. 10 is a sectional view of a dielectric BUSHING ~~bush~~ according to a first modification of the first embodiment;

Fig. 11 is a sectional view of a dielectric BUSHING ~~bush~~ according to a second modification of the first embodiment;

Fig. 12 is a sectional view of a dielectric BUSHING ~~bush~~ according to a third modification of the first embodiment;

Fig. 13 is a perspective view of the dielectric BUSHING ~~bush~~ according to the third modification of the first embodiment; and

Fig. 14 is a sectional view of a dielectric BUSHING ~~bush~~ according to a fourth modification of the first embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before the description of the present invention proceeds, it is to be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

Description will now be given of the first embodiment of the present invention with reference to Figs. 1 to 3.

Fig. 1 shows a cross sectional view of a plasma processing apparatus for use in the first embodiment of the present invention. In Fig. 1, a specified gas is introduced from a gas supply device 2 into a vacuum chamber 1 while being exhausted therefrom by a pump 3 serving as an

example of an exhauster to keep the vacuum chamber 1 within a specified pressure. Under such a condition, high-frequency power of 100 MHz can be supplied by a high-frequency power source ~~for antenna~~ 4 to an antenna 5, as one example of a plasma source, PROTRUDING ~~protruded~~ into the vacuum chamber 1 to generate plasma~~s~~ in the vacuum chamber 1 to perform plasma processing of a substrate 7 mounted on a substrate electrode 6. In addition, there is provided a high-frequency power source ~~for substrate electrode~~ 8 for supplying high-frequency power to the substrate electrode 6, which enables control of ion energy REACHING ~~reached~~ the substrate 7. High-frequency voltage~~s~~ supplied to the antenna 5 is guided by a feed bar 9 to a central part of the antenna 5. A plurality of areas located not in the center nor the vicinity of the antenna 5 ~~and a plane~~ (UPPER CHAMBER WALL) 1A ~~facing the substrate 7~~ of the vacuum chamber 1 FACING THE SUBSTRATE 7 are short-circuited by short pins 10. A dielectric plate 11 is interposed between the antenna 5 and the vacuum chamber 1. Through penetrating holes provided on the dielectric plate 11, the feed bar 9 and the short pins 10 connect the antenna 5 to the high-frequency power source ~~for antenna~~ 4 and CONNECT the antenna 5 to a vacuum chamber 1, respectively. The surface of the antenna 5 is covered with an insulative cover 12. ~~There is provided~~ A ~~a~~ plasma trap 15 made up of a groove-shaped space IS ARRANGED between the dielectric plate 11 and a

dielectric ~~ring~~ 13 ~~placed~~ in the vicinity of the dielectric plate 11, and MADE OF a groove-shaped space between the antenna 5 and a conduction ring 14 ~~placed~~ in the vicinity of the antenna 5. By the gas supply device 2, the gas is introduced into the vacuum chamber 1 through a gas supply hole 18 (See Fig. 2) provided ~~on~~ IN a dielectric ~~bush~~ BUSHING 17, ~~as~~ WHICH IS one example of a dielectric tube. THE BUSHING 17 IS attached to a metal ring 16 which constitutes a part of a side wall of the vacuum chamber 1. THE METAL RING 16 ~~and~~ has a ring-shaped gas passage 16a therein and is made of metal such as aluminum or stainless steel.

Fig. 2 shows a detail view around the dielectric ~~bush~~ BUSHING 17 made of ceramic as one example. On the side of the inner wall of ~~the~~ A vacuum chamber 1, there is provided a spot facing for screw driver 19 (See Fig. 9) for rotating and screwing the dielectric ~~bush~~ BUSHING 17 ~~in~~ INTO the metal ring 16. The metal ring 16 is equipped with a tap 20 for screwing in the dielectric ~~bush~~ BUSHING 17. The dielectric ~~bush~~ BUSHING 17 has the shape of a bolt, ~~The dielectric bush 17~~ AND ~~is protruded~~ PROTRUDES by 5mm from the surface of the metal ring 16. The dielectric ~~bush~~ BUSHING 17 is disposed such that it covers an edge 21 of a hole ~~provided~~ on the metal ring 16. THE ~~A~~ gas supply hole 18 ~~given on~~ IN the dielectric bush 17 is 0.5mm in diameter. The metal ring 16 is equipped with A total OF EIGHT ~~8~~ dielectric bushes 17, making it possible to blow out gas into the vacuum chamber 1 in AN approximately isotropic direction. Fig. 3 shows a

plan~~e~~ view of the antenna 5. In Fig. 3, the short pins 10 are put in three locations. Each of three short pins 10 is disposed at equal intervals around the center of the antenna 5.

With the plasma processing apparatus shown in Figs. 1 to 3, a substrate having an iridium film was etched. Etching was conducted under the conditions of argon gas of 260sccm and chlorine gas of 20sccm, A pressure of 0.3Pa, antenna power of 1500W, and substrate electrode power of 400W. Total gas flow rate was 260+20 = 280sccm, and the number of gas supply holes was ~~8~~ EIGHT, so that THE gas supply flow rate per gas supply hole was 280/8 = 35sccm. As a result of etching under such conditions, hollow cathode discharge in each gas supply hole 18 did not occur, and therefore A good discharge condition was obtained.

The reason why the hollow cathode discharge could be suppressed may be that high-frequency electric fields in each gas supply hole 18 were weakened compared to those in the prior art example. It can be considered that an inclination ~~to~~ FOR occurrence of the hollow cathode discharge is largely influenced by high-frequency electric fields ~~reached~~ REACHING the gas supply holes as ~~well as~~ A gas velocity or pressure gradient. It can be ~~considered~~ UNDERSTOOD that ~~composing~~ FORMING the vicinity of each gas supply hole 18 ~~of~~ a dielectric substance (THE DIELECTRIC BUSHING) and protruding the dielectric ~~bush~~ BUSHING 17 by 5mm from

the surface of the metal ring 16 WILL weaken high-frequency electric fields in an outlet of each gas supply hole 18, thereby enabling suppression of the hollow cathode discharge.

The above-described first embodiment of the present invention is just one example of a number of variations available in the shape of the vacuum chamber as well as the shape and disposition of the antenna within an applicable range of the present invention. It will be understood that diverse variations other than the one exemplified ~~here~~ above are available in APPLYING ~~application of~~ the present invention.

In the above described first embodiment of the present invention, high-frequency voltage is supplied to the antenna through a penetrating hole given near the center of the dielectric plate, and the antenna and the vacuum chamber are short-circuited with the short pins through penetrating holes which are ~~given at an area~~ located not in the center nor the vicinity of the dielectric plate and which are disposed at approximately equal intervals around the center of the antenna. Such construction makes it possible to increase isotropy of plasma~~s~~. In the case of handling a small substrate, the present invention ensures sufficiently high inplane uniformity without THE use of the short pins.

Further, in the first embodiment of the present invention, there has been ~~described~~ the case of processing the substrate in ~~the~~ A state ~~that~~ IN WHICH the plasma distribution on ~~to~~ the substrate was controlled by the circular and groove-shaped plasma trap provided between the antenna and the vacuum chamber. Such construction contributes to increased uniformity of THE plasma~~s~~. In the case of handling a small substrate, the present invention ensures sufficiently high inplane uniformity without ~~use of~~ USING the plasma trap.

The present invention is also effective when using ~~as an antenna~~ the coil 23 AS THE ANTENNA, AS in the case with the inductively coupled plasma source shown in Fig. 8 ~~describing the~~ SHOWING A prior art example, ~~or~~ ALTERNATIVELY, THE PRESENT INVENTION IS EFFECTIVE WHEN USING an electromagnetic radiation antenna 26, AS in the case with a surface wave plasma source shown in Fig. 4.

~~Further~~ In the first embodiment of the present invention shown above, the metal body with the dielectric ~~bush~~ BUSHING embedded THEREIN is the ring that constitutes a part of the side wall of the vacuum chamber. Such construction is also effective when, as shown in Fig. 5, ~~a~~ THE metal body with ~~a~~ dielectric ~~bush~~ BUSHING ~~embedded~~ embedded THEREIN is a conduction ring 14 ~~disposed~~ ARRANGED so as to ~~constitute~~ FORM a plasma trap IS between the metal body and the antenna.

Description will now be given of a second embodiment of the present invention with reference to Figs.

6 to 7.

Fig. 6 is a cross sectional view of a plasma processing apparatus for use in the second embodiment of the present invention. In Fig. 6, a specified gas is introduced from a gas supply device 2 into a vacuum chamber 1 while being exhausted therefrom by a pump 3 serving as an example of an exhauster to keep the vacuum chamber 1 within a specified pressure. Under such a condition, high-frequency power of 13.56 MHz can be supplied by a high-frequency power source ~~for substrate electrode~~ 8 to a substrate electrode 6 to generate plasma~~s~~ in the vacuum chamber 1 to perform plasma processing of a substrate 7 mounted on a substrate electrode 6. There is provided a facing electrode 22 that faces the substrate electrode 6 and has therein a gas passage 22a connected to a plurality of holes with taps 20. The gas is introduced into the vacuum chamber 1 through a gas supply hole 18 (See Fig. 7) ~~given to a~~ IN EACH dielectric ~~bush~~ BUSHING 17, ~~as~~ WHICH IS one example of a dielectric tube, placed on the facing electrode 22.

Fig. 7 shows a detail view around the dielectric ~~bush~~ BUSHING 17 made of ceramic, ~~as one~~ FOR example. On the side of the inner wall of the vacuum chamber 1, the dielectric ~~bush~~ BUSHING 17 has a spot facing for A screw driver ~~19~~ (See Fig. 9) for rotating and screwing the dielectric ~~bush~~ BUSHING 17 in the facing electrode 22. The facing electrode 22 is equipped with a

tap 20 for screwing in the dielectric BUSHING ~~bush~~ 17. The dielectric BUSHING ~~bush~~ 17 has the shape of a bolt S, ~~The dielectric~~ AND PROTRUDES ~~bush 17 is protruded~~ by 5mm from the surface of the facing electrode 22. The dielectric BUSHING ~~bush~~ 17 is ARRANGED SO ~~disposed such~~ that it covers an edge 21 of a hole provided on the facing electrode 22. A gas supply hole 18 IN ~~given on~~ the dielectric BUSHING ~~bush~~ 17 is 0.5mm in diameter. The ~~facing~~ electrode 22 is equipped with A total OF 80 dielectric BUSHINGS ~~bushes~~ 17, making it possible to blow out gas toward a substrate in the vacuum chamber 1.

With the plasma processing apparatus shown in Figs. 6 to 7, a substrate having an aluminum film was etched. Etching was conducted under the conditions of chlorine gas of 200sccm, boron trichloride gas of 600sccm, argon gas OF 800sccm, A pressure of 5Pa, and substrate electrode power of 4kW. Total gas flow rate was 200+600+800 = 1600sccm, and the number of gas supply holes was 80, so that gas supply flow rate per gas supply hole was 1600/80 = 20sccm. As a result of etching under such conditions, A hollow cathode discharge in each gas supply hole 18 did not occur, and therefore good discharge condition was obtained.

The reason why the hollow cathode discharge could be suppressed may be that high-frequency electric fields in each gas supply hole 18 were weakened compared to those ~~in~~ the prior art example. ~~It can be considered that~~ An

inclination ~~to~~ FOR occurrence of the hollow cathode discharge is largely influenced by high-frequency electric fields ~~reached~~ REACHING the gas supply holes, as well as THE gas velocity or pressure gradient. It can be ~~considered~~ UNDERSTOOD that ~~composing~~ FORMING the vicinity of each gas supply hole 18 ~~of~~ a dielectric substance (SUCH AS A DIELECTRIC BUSHING) and protruding the dielectric ~~bush~~ BUSHING 17 by 5mm from the surface of the facing electrode 22 WILL weaken high-frequency electric fields in an outlet of each gas supply hole 18, thereby enabling suppression of the hollow cathode discharge.

In the above described embodiments of the present invention, the dielectric ~~bush~~ BUSHING is a bolt screwed in the tap ~~given to~~ IN the metal body or the facing electrode. However, the dielectric ~~bush~~ BUSHING is not necessarily in the shape of a bolt, but may be embedded ~~to~~ INTO the metal body or the facing electrode in the shape of a wedge. The dielectric ~~bush~~ BUSHING in the shape of a bolt has an advantage that replacement thereof as an expendable component is easy.

Further, ~~there~~ IT has been described that the dielectric ~~bush had~~ BUSHING HAS a spot facing for A screw driver on the side of the inner wall of the vacuum chamber for rotating and screwing the dielectric ~~bush~~ BUSHING in the metal plate or the facing electrode. However, other than the spot facing for THE screw driver, the present invention may adopt shapes for various tools such as wrenches. It goes without saying

that the spot facing is not necessary if the dielectric BUSHING ~~bush~~ is wedge-shaped.

As described above, the dielectric BUSHING ~~bush~~ ~~is~~ PROTRUDES ~~protruded~~ by 5mm from the surface of the metal body or the facing electrode. Since an experimental result proves that APPROXIMATELY ~~approx.~~ 0.5mm or more protrusion is desirable, the length of protrusion of the dielectric BUSHING ~~bush~~ is preferably within this range. However, excessive protrusion may lead to breakage of the dielectric BUSHING ~~bush,~~ ~~and~~ therefore the dielectric BUSHING ~~bush~~ may preferably PROTRUDE ~~be protruded~~ by APPROXIMATELY ~~approx.~~ 20mm or less. Accordingly, an optimum length of protrusion of the dielectric BUSHING ~~bush~~ is ~~considered to be~~ about 1 to 10mm, which ~~surely~~ ensures suppression of hollow cathode discharge and prevents breakage of the dielectric BUSHING ~~bush~~.

As described above, the dielectric BUSHING ~~bush~~ is ARRANGED SO ~~disposed such~~ that it covers the edge of the hole provided IN ~~on~~ the metal body or the facing electrode. Such construction is preferable since it can effectively prevent the edge of the hole provided IN ~~on~~ the metal body or the facing electrode from deteriorating due to exposure to plasma~~s~~ for a long period of time.

As described above, the hole IN ~~given on~~ the dielectric BUSHING ~~bush~~ is 0.5mm in diameter. Since an experimental result proves that a smaller hole reduces a tendency FOR ~~to~~ occurrence of hollow cathode discharge, the

size of the hole is preferably about 2mm or less. However too small a hole increases difficulty in processability, and therefore the diameter of the hole is preferably 0.2mm or more. Accordingly, an optimum diameter of the hole is considered to be about 0.4 to 0.8mm, which ensures suppression of hollow cathode discharge and facilitates processing.

~~There were described the~~ Cases IN WHICH ~~where~~ ~~the~~ gas supply flow ~~rate per hole~~ FOR ~~given to~~ the dielectric BUSHING ~~bush~~ was 35sccm and 20sccm HAVE BEEN DESCRIBED. Since an experimental result proves that A smaller gas supply flow rate per hole reduces a tendency FOR ~~to~~ occurrence of hollow cathode discharge, gas supply flow rate per hole is preferably around 200sccm or less. For more secure suppression of hollow cathode discharge, gas supply flow rate per hole FOR ~~given to~~ the dielectric BUSHING ~~bush~~ is preferably 50sccm or less. To meet~~s~~ such conditions, AN increase IN ~~of~~ the number ~~of the~~ gas supply holes is effective, as well as A decrease IN THE ~~of~~ gas flow rate in plasma processing.

As described above, a gas for use in the present invention is a mixed gas mainly composed of an argon gas. It HAS BEEN ~~is~~ empirically proveN~~d~~ that a tendency FOR ~~to~~ occurrence of hollow cathode discharge differs by types of gases, and an argon gas considerably increases the tendency. Accordingly, the present invention is particularly effective when a

mixed gas mainly composed of an argon gas is in use. In the case of using other gases, the present invention is also quite effective for suppression of hollow cathode discharge.

~~There were also described the~~ Cases ~~where~~ IN WHICH the pressure in the vacuum chamber was 0.3Pa and 5Pa HAVE ALSO BEEN DESCRIBED. Since lower pressure in the vacuum chamber increases a tendency ~~to~~ FOR occurrence of hollow cathode discharge, the present invention is effective when the pressure in the vacuum chamber is 10 Pa or less. The present invention is further effective when the pressure in the vacuum chamber is 1Pa or less.

~~There were described the~~ Cases ~~where~~ IN WHICH a frequency of high-frequency power applied to the antenna, the substrate electrode, or the facing electrode was 100MHz or 13.56MHz HAVE ALSO BEEN DESCRIBED. In plasma processing with low pressure, there can be used high-frequency power ranging from 100kHz to 3GHz, and over such a broad range, the present invention is effective. However, with a higher frequency of high-frequency power, electromagnetic waves tend to spread in a wider range, which tends to increase high-frequency electric fields in the gas supply hole. Accordingly, the present invention is effective when ~~a~~ THE frequency of high frequency power is high, especially in the range from 50MHz to 3GHz.

Fig. 10 is a sectional view of a dielectric ~~bush~~ BUSHING 17A according to a first modification of the first embodiment. The dielectric ~~bush~~ BUSHING 17A has a spot facing 17g at the inner end side thereof with the diameter of the spot facing ~~lager~~ BEING LARGER than the diameter of the gas supply hole 18, and with the spot facing 17g BEING connected to the gas passage 16a. The ~~distance~~ LENGTH of the gas supply hole 18 is not less than 1mm, preferably, so as to surely obtain the above effects.

Fig. 11 is a sectional view of a dielectric ~~bush~~ BUSHING 17B according to a second modification of the first embodiment, ~~where~~ IN WHICH the dielectric ~~bush~~ BUSHING 17B ~~is~~ DOES not protrude~~s~~ from the surface of the metal ring 16 in a case where Ar gas and the antenna power of 500W or less are used.

Figs. 12 and 13 are a sectional view and a perspective view of a dielectric ~~bush~~ BUSHING 17C according to a third modification of the first embodiment, ~~where~~ IN WHICH the dielectric ~~bush~~ BUSHING 17C has a LATERAL projection 17h, instead of a screw portion, for engaging ~~with~~ a recess 16h. The projection 17h can pass through a groove 16j of the metal ring 16, and then the dielectric ~~bush~~ BUSHING 17C is rotated to engage the projection 17h with the recess 16h. ~~so that~~ THEREFORE, the dielectric ~~bush~~ BUSHING 17C is not ~~taken out~~ REMOVED from the metal ring 16 in its axial direction. When the dielectric ~~bush~~ BUSHING 17C is ~~taken out~~ REMOVED from the metal ring 16, the dielectric ~~bush~~ BUSHING 17C

is rotated to ~~insert~~ ALIGN the projection 17h ~~into~~ WITH the groove 16j, so that the dielectric ~~bush~~ bushing 17C is ~~taken out~~ REMOVED from the metal ring 16 ~~in~~ ALONG its axial direction.

Fig. 14 is a sectional view of a dielectric ~~bush~~ BUSHING 17D according to a fourth modification of the first embodiment, ~~where~~ IN WHICH the ~~whole of the~~ ENTIRE dielectric ~~bush~~ BUSHING 17D ~~is~~ ~~protruded~~ PROTRUDES from the surface of the metal ring 16 with the gas supply hole 18 connected to a gas hole 16i of the metal ring 16.

As is clear from the above description, according to the plasma processing method in the present invention, the gas is introduced into the vacuum chamber while being exhausted therefrom to keep the vacuum chamber within a specified pressure. Under such a condition, high-frequency power with a frequency ranging from 100kHz to 3GHz is applied to the plasma source, such as the antenna, ~~provided~~ so as to face the substrate mounted on the substrate electrode in the vacuum chamber to generate plasma~~s~~ in the vacuum chamber to perform plasma processing of the substrate. In this method, the gas ~~is~~ supplied to the vacuum chamber through the hole ~~given to~~ IN the dielectric ~~bush~~ BUSHING embedded in the metal body, which implements plasma processing ~~that reduces a tendency to~~ FOR REDUCING THE occurrence of hollow cathode discharge in the gas supply hole.

According to the plasma processing method in the

present invention, the gas is introduced into the vacuum chamber while being exhausted therefrom to keep the vacuum chamber within a specified pressure. Under such a condition, high-frequency power with a frequency ranging from 100kHz to 3GHz is applied to the substrate electrode or the facing electrode provided so as to face the substrate electrode in the vacuum chamber to generate plasma~~s~~ in the vacuum chamber to perform plasma processing of a substrate mounted on the substrate electrode. In this method, the gas is supplied to the vacuum chamber through the hole ~~given to~~ IN the dielectric ~~bush~~ BUSHING embedded in the facing electrode, which implements plasma processing that reduces a tendency ~~to~~ FOR occurrence of hollow cathode discharge in the gas supply hole.

According to the plasma processing apparatus in the present invention, the plasma processing apparatus is made up of the vacuum chamber, the gas supply device for supplying the gas into the vacuum chamber, the exhauster for exhausting the gas from the vacuum chamber, the substrate electrode for mounting the substrate in the vacuum chamber, the plasma source (such as the antenna) ~~provided~~ ARRANGED so as to face the substrate electrode, and the high-frequency power source for supplying high-frequency power with a frequency ranging from 100kHz to 3GHz to the antenna. In this device, the gas is supplied to the vacuum

chamber through the hole ~~given to~~ IN the dielectric ~~bush~~ BUSHING embedded in the metal body, ~~which~~ implements plasma processing that reduces a tendency ~~to~~ FOR occurrence of hollow cathode discharge in the gas supply hole.

According to the plasma processing apparatus in the present invention, the plasma processing apparatus is made up of the vacuum chamber, the gas supply device for supplying the gas into the vacuum chamber, the exhauster for exhausting the gas from the vacuum chamber, the substrate electrode for mounting ~~the~~ substrate in the vacuum chamber, the facing electrode ~~provided~~ ARRANGED so as to face the substrate electrode, and the high-frequency power source for supplying high-frequency power with a frequency ranging from 100kHz to 3GHz to the substrate electrode or the facing electrode. In this device, the gas is supplied to the ~~vacuum~~ chamber through the hole ~~given to~~ IN the dielectric ~~bush~~ BUSHING embedded in the facing electrode, which implements plasma processing that reduces a tendency ~~to~~ FOR occurrence of hollow cathode discharge in the gas supply hole.

Although the present invention has been fully described in connection with the preferred embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and

modifications are to be understood as included within the scope of the present invention as defined by the appended claims unless they depart therefrom.

ABSTRACT OF THE DISCLOSURE

A plasma processing method includes introducing a gas into a vacuum chamber through a hole of a dielectric tube attached to a metal body fixed to the vacuum chamber while exhausting from the vacuum chamber ~~to~~ keep the vacuum chamber within a specified pressure. ~~and applying~~ High-frequency power with a frequency ranging from 100kHz to 3GHz IS APPLIED to a plasma source provided so as to face a substrate mounted on a substrate electrode in the vacuum chamber to generate plasma~~s~~ in the vacuum chamber to perform plasma processing of the substrate.